# The Effects of Oil Contamination on the Consolidation Properties of Lateritic Soil

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***Abstract***

Appreciable quantities of used motor oil spills are common at and around mechanic workshops. Laboratory testing program was carried out to determine the effect of used motor oil contamination on the strength and consolidation properties of lateritic soils. Contaminated specimens were prepared by mixing the soil with used motor oil based on weight of dry soil in order to evaluate the usefulness or otherwise of oil contaminated soils in engineering construction. The results indicated a decrease in the unconfined compressive strength (UCS), coefficient of consolidation, $c_v$ and coefficient of volume compressibility, $m_v$, up to 6% oil content. The UCS of the specimens containing, 0, 2, 4, and 6% oil content was 154, 185, 180, 151 and 103 kN/m$^2$, while the coefficient of consolidation, $c_v$ and coefficient of volume compressibility, $m_v$, decreased to 373, 75, 27 and 12 m$^2$/year and 157 x 10$^{-6}$, 334 x 10$^{-5}$, 305 x 10$^{-5}$ and 540 x 10$^{-6}$ m$^2$/MN, respectively at 0, 2, 4 and 6% oil content. The results of laboratory tests showed that properties of the soil were immensely impaired on contamination with oil.

***Keywords:***

*Coefficient of Consolidation; Coefficient of Volume Compressibility; Lateritic Soil; Unconfined Compressive Strength (UCS); Used Motor Oil*

## Introduction

Used motor oil contaminations of soil are common wherever motor mechanic workshops are located. It has been reported that the bearing capacity of such soils is drastically reduced and made engineering structures unsuitable to run, or plant growth by reducing the availability of nutrients or by increasing toxic contents in the soil (Euchun and Braja, 2001).

In addition, the magnitude of crude oil pollution and damage caused/triggered by multi-national oil companies operation in the Niger Delta of Nigeria has precipitated a slow poisoning of waters in the region, destruction of vegetation and agricultural lands which occur during oil spills, Marr and Hooper (1998); Corbett (2004); Sahel (2007) and Ijimdiya (2010a,b).

Oil spills in Nigeria occur due to a number of causes including: corrosion of pipelines and tankers (accounting for 50% of all spills), sabotage (28%) and oil production operations (21%), with 1% of spills being accounted for inadequate or non-functional production equipment Francesca (1998).

Oil contaminated soil (OCS) has been defined by Colorado Department of Health and Environment (2003), as any earthen material or artificial fill that has human or natural alteration of its physical, chemical, biological or radiological integrity resulting from the introduction of crude oil, any fraction or derivative (such as gasoline, diesel, or used motor oil) or any oil based product. The production, dumping and pollution of oil waste wreak havoc on the surrounding wildlife and habitat. It is in this vein that geotechnical engineers are facing increasing challenges as a result of oil spills and hence it is needed to develop the methodologies for such soils on test, identification, classification, utilization and remediation technologies.

OCS could also be the waste product produced by cleaning up oil spills or due to oil spillage. Left unattended, these soils pose a threat to human health and environment. Numerous remedial technologies are available to eliminate or significantly reduce the risk that OCS poses, such as: conversion of oily soil into road base material or a topping layer for car parks and roads after mixing with aggregate or a consolidation agent. Other methods include containment in large burial sites, incineration, biological methods, absorption methods, soil washing methods, and vacuum extraction. Most of these methods are expensive and uneconomical, considering the large quantities of materials involved.

Lateritic soil as a soil group rather than well defined materials is the most common found in the leached soils of the humid tropics where they were first studied. Lateritic soils are formed under weathering

systems productive of the process of laterization (Osinubi et al., 2007). The most important characterization is the decomposition of ferro-aluminium silicate minerals and the permanent deposition of sesquioxide (i.e., oxides of iron and Aluminium - $Fe_2O_3$ and $Al_2O_3$) within the profile to form the horizon of materials is known as laterite.

The term "laterization" describes the processes in which laterite soils is produced (Osinubi et al., 2007). Construction Industry Research and Information Association (CIRIA, 1988) proposed the following definition for lateritic soils which states that 'laterite in all its form is a highly weathered natural material formed by the concentration of the hydrated oxides of iron and aluminium. This concentration may be by residual accumulation or by solution, movement and chemical precipitation. For the purpose of this study a modified definition is used which states that *laterite is a highly weathered material rich in secondary oxides of any of iron, aluminium, manganese, or titanium* (Ijimdiya, 2011).

The purpose of this study was to investigate the effect of used oil on the strength and compressibility behavior of lateritic soils. Laboratory testing programme was carried out on a reference soil-laterite taken from Shika – Zaria, Kaduna State, Nigeria. The soil was contaminated with used motor oil at stepped concentrations of 0, 2, 4, 6 and 8% by dry weight of soil (Al-Sanad et al., 1995). Similar researches were carried out by Shin and Das (2001) on the bearing capacity of unsaturated oil-contaminated sand in Kuwait who (2001) reported that the bearing capacity of oil-contaminated sands drastically reduced.

During the last two decades, the results of a number of studies related to the physical properties and behaviour of oil and petroleum contaminated soils have been published (e.g., Al-Sanad et al., 1995; Aiban, 1997; Meegoda and Ratnaweera,1994; Mohammed, 1995; Khamehchiyun, et al., 2006; Ijimdiya, 2007, 2010a,b, 2011).

## Materials and Method

### *Materials*

#### *1) Soil*

The soil used in this study is a natural reddish brown laterite taken from a burrow pit at Shika in Zaria (lat. 11o15N & long 7o45oE) or 0344054N and 1238202E UTM, obtained using a global positioning system (GPS). It was collected as a disturbed sample obtained at a depth of 0.5 m below the ground. A study of the geological and soil maps of Nigeria shows that the natural material obtained belongs to the group of ferruginous tropical soils derived from acid igneous and metamorphic rocks (Osinubi, 1998a, b). The results of laboratory tests carried out on the natural and oil contaminated soil samples are given in Tables 2 – 6.

The approach used in this study is that of artificial contamination of the soil with used oil in the laboratory in agreement with other researchers (Al-Sanad, 1995 and Aiban 1998) which may be the limitation of the study. However, the soil samples contaminated by oil obtained from the field may be utilized.

#### *2) Used Oil*

The petroleum product utilized in this study is used motor oil which was collected from Oando lubrication workshop opposite Ahmadu Bello University, main campus, Zaria, Kaduna State, Nigeria. The oil was collected in a closed container and stored in a cool dry place. The physical properties of the oil are shown in Table 1, such as specific gravity, flash point, fire point, viscosity and density are, 0.70, 1680C, 2200C, 1.17 cP, and 0.76 g/cm3.

### *Methods*

TABLE 1 PHYSICAL PROPERTIES OF THE NATURAL SOIL

| *Characteristics* | *Quantity* |
|---|---|
| % Passing B.S. No 200 sieve | 86.90 |
| Liquid Limit (LL), (%) | 37.24 |
| Plastic Limit (PL), (%) | 21.20 |
| Plasticity Index (PI), (%) | 16.04 |
| Linear Shrinkage (LS), (%) | 9.40 |
| AASHTO Classification | A-6(16) |
| USCS | CL |
| Specific gravity (GS) | 2.69 |
| Natural Moisture Content, (%) | 10.5 |
| pH | 6.1 |

TABLE 2 PARTICLE SIZE DISTRIBUTION OF NATURAL AND OIL CONTAMINATED SOIL

| *sieve size(mm)* | *0% oil* | *2% oil* | *4% oil* | 6% oil |
|---|---|---|---|---|
| 0.075 | 86.9 | 3.7 | 0.2 | 0.0 |
| 0.15 | 90.7 | 21.1 | 6.9 | 0.0 |
| 0.21 | 91.8 | 25.1 | 13.6 | 1.4 |
| 0.3 | 92.8 | 28.5 | 20.4 | 4.0 |
| 0.42 | 93.8 | 32.4 | 24.7 | 10.8 |
| 0.6 | 95.7 | 53.3 | 46.2 | 47.8 |
| 1.2 | 96.5 | 67.8 | 61.8 | 61.2 |
| 2.4 | 96.9 | 82.3 | 76.8 | 75.1 |

TABLE 3 UNCONFINED COMPRESSIVE STRENGTH WITH HIGHER OIL CONTENTS

| ***Oil content*** (%) | 0 | 2 | 4 | 6 | 8 |
|---|---|---|---|---|---|
| UCS (kN/m²) | 154.4 | 185.8 | 180.1 | 151.8 | 103.8 |

TABLE 4 VOID RATIO WITH HIGHER OIL CONTENTS UNDER VARYING LOADS

| ***Pressure*** | ***Oil content (%)*** | | | | |
|---|---|---|---|---|---|
| ***(kN/m²)*** | 0 | 2 | 4 | 6 | 8 |
| 50 | 0.335741 | 0.360884 | 0.329049 | 0.237694 | 0.377693 |
| 100 | 0.335562 | 0.360767 | 0.328749 | 0.237043 | 0.376161 |
| 200 | 0.33418 | 0.358912 | 0.327805 | 0.236807 | 0.374907 |
| 400 | 0.333067 | 0.3565 | 0.3565 | 0.235993 | 0.374235 |
| 800 | 0.332308 | 0.352875 | 0.324608 | 0.234342 | 0.37256 |
| 1600 | 0.332141 | 0.352423 | 0.322818 | 0.233808 | 0.372446 |

TABLE 5 COEFFICIENT OF VOLUME COMPRESSIBILITY WITH HIGHER OIL CONTENTS

| ***Pressure*** | ***Oil content (%)*** | | | | |
|---|---|---|---|---|---|
| ***(kN/m²)*** | 0 | 2 | 4 | 6 | 8 |
| 50 | 0.003877 | 0.001709 | 0.014314 | 0.004948 | 0.018975 |
| 100 | 0.002688 | 0.001709 | 0.004509 | 0.010517 | 0.022264 |
| 200 | 0.010354 | 0.013654 | 0.00711 | 0.001914 | 0.009118 |
| 400 | 0.004177 | 0.008889 | 0.006087 | 0.003291 | 0.002448 |
| 800 | 0.001424 | 0.006699 | 0.002987 | 0.003344 | 0.003351 |
| 1600 | 0.000157 | 0.003344 | 0.003051 | 0.000541 | 0.000103 |

TABLE 6 COEFFICIENT OF CONSOLIDATION WITH HIGHER OIL CONTENTS

| ***Pressure*** | ***Oil content (%)*** | | | | | |
|---|---|---|---|---|---|---|
| ***(kN/m²)*** | 50 | 100 | 200 | 400 | 800 | 1600 |
| 0 | 234.6045 | 55.18295 | 187.4028 | 58.45396 | 10.37723 | 373.3207 |
| 2 | 15.70663 | 76.00712 | 94.87134 | 472.8699 | 371.0506 | 75.09684 |
| 4 | 260.5358 | 374.8186 | 585.1062 | 55.28802 | 582.5737 | 27.18559 |
| 6 | 1501.389 | 2344.107 | 70.84845 | 585.1097 | 2335.776 | 466.3294 |
| 8 | 13.88366 | 234.5988 | 586.411 | 65.15017 | 146.5698 | 128.4874 |

## Discussion of Results

### *Effect of Oil Contamination on the Particle Size Distribution of Lateritic Soil*

The uncontaminated soil was pulverized and passed through BS. No. 4 sieve as specified by (Head, 1980) for the purpose of removing excess clods from clayey soil. The soil was then mixed with oil at 2, 4 and 6% oil contents. This resulted in the formation of aggregates, clods, and lumps or otherwise called crumbs, in agreement with (Osinubi, and Ijimdiya, 2009). The soil particles are glued together by the oil.

The particle size distribution curves for both the uncontaminated and contaminated soils are shown in Fig. 1. It was observed that there was a great reduction in the percentage of fines with increase in the oil content. The reduction in the proportion of silt or the fine fraction could be due to the bonding both of the silt sizes to form pseudo-sand sizes and of the sand sizes to form larger sand or clog sizes.

The most probable reason for the decrease could be due to the fact that the oil affected the physico-chemical nature of the soil particularly the clayey fraction.

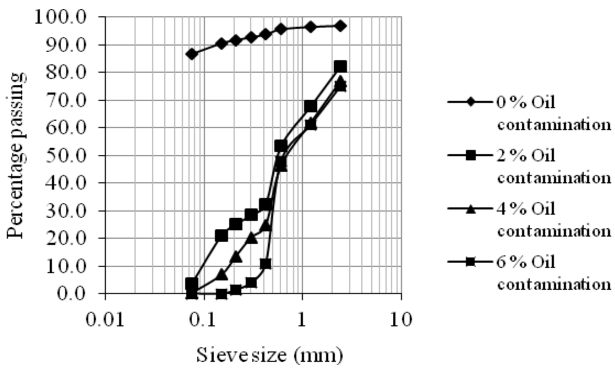


FIG. 1 PARTICLE SIZE DISTRIBUTION CURVES OF NATURAL AND OIL CONTAMINATED LATERITIC SOIL

### *Effect of Oil Content on the UCS*

The variation of UCS with oil content is shown in Fig. 2. The value of UCS of the natural soil was 154.4 kN/m². On addition of 2% oil, an increase in UCS was observed to a value of 185.8 kN/m². UCS decreased slightly to a value of 180.7 kN/m² at 4% oil content. Further increase in oil content resulted in a corresponding decrease in the value of UCS to a minimum value of 101.8 kN/m² at 8% oil content.

The initial increase in UCS for samples containing 2% oil content could be attributed to the rearrangement of pseudo sized particles formed from the bonded fines fraction in between the larger sand fraction to achieve an increased bonding between the particles leading to/resulting in a greater load resistance. With further increase in oil content, there was a reduced inter-particle friction due to the lubrication effect provided by the oil leading to failure within a shorter period of time.

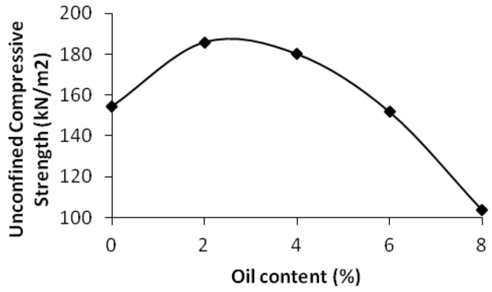


FIG. 2 VARIATION OF UCS WITH OIL CONTENT

### *Effect of Oil Content on the Void Ratio*

The effect oil content on the void ratio of the oil contaminated soil is shown in Fig. 3. The void of the natural soil increased from 0.34 to 0.36 when contaminated with 2% oil content and subjected to 50 kN/m² loading. Further increase in oil content up to 6% led to a decrease in the void ratio to a minimum value of 0.23. At 8% oil content, there was a sharp increase in the void ratio to a value of 0.38. Similar results were obtained when varying loading cases were applied as shown in Fig. 4. The probable reason for the initial increase in the void ratio at 2% oil content could be due to the great reduction in the percentage of fines as they were bonded to form pseudo-sand and sand sized particles which created larger void spaces in the soil matrix as shown in Fig. 1. This is in agreement with the findings of (Al-Sanad, 1995 and Ijimdiya, 2011).

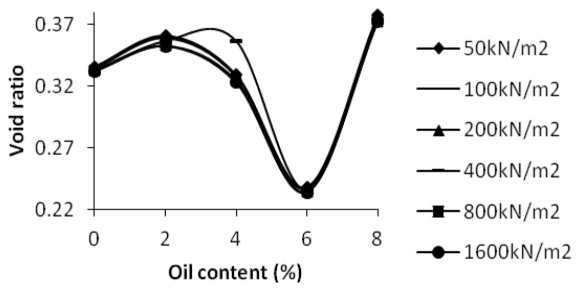


FIG. 3 VARIATION OF VOID RATIO WITH OIL CONTENT

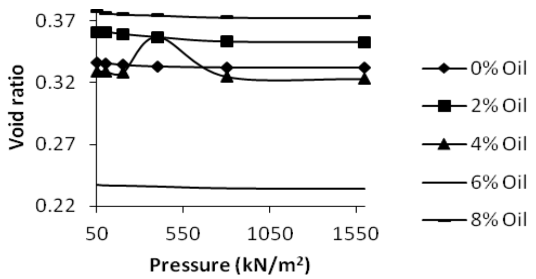


FIG. 4 VARIATION OF VOID RATIO WITH PRESSURE

### *Effect of Oil Content on the Coefficient of Volume Compressibility*

The effect of oil content on the coefficient of volume compressibility $M_v$ is shown in Fig. 5. Generally, there was an initial increase in the values of $M_v$ at 2% oil content. The value of $M_v$ for the natural soil increased from 0.0039 to 0.019 at 8% oil content applying 50kN/m² loading. With further increase in oil content up to 6%, there was a decrease in the values of $M_v$ recorded. However, the values of $M_v$ decreased with increase in the loading pressures as shown in Fig. 6. Further increase in oil content up to 8% led to a corresponding increase in the values of $M_v$. The probable reason for the initial increase in $M_v$ at 2% oil content under varying loading conditions could be due to the rearrangement of the newly bonded soil particles into the macro voids created as the soil was compressed. However, a decrease in the values of $M_v$ with higher oil contents may have been due to the presence of fewer voids as a more bonded soil matrix was formed with higher oil content hence the contaminated soil experienced little compression, while the excess oil was extruded from the sample. It is pertinent to observe that the values of $M_v$ decreased under increasing loading pressures as shown in Fig. 6. The probable reason could be as a result of higher weights and there was no available void to be compressed, which triggered/caused the extrusion of oil from the tested sample.

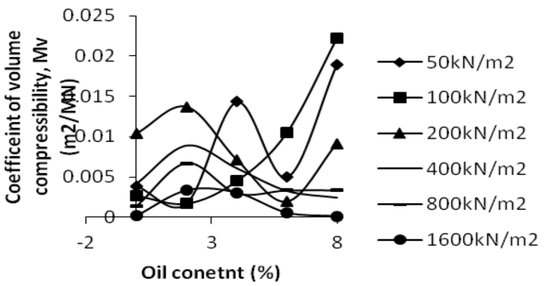


FIG. 5 VARIATION OF COEFFICEINT OF VOLUME COMPRESSIBILITY WITH OIL CONTENT

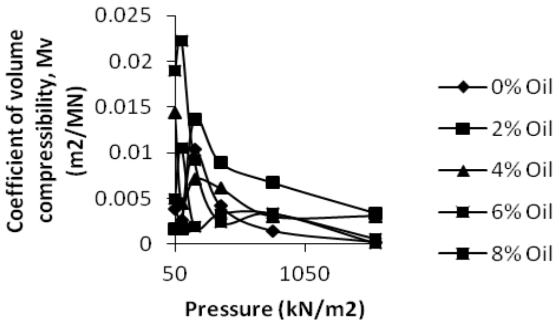


FIG. 6 VARIATION OF COEFFICIENT VOLUME COMPRESSIBILITY WITH PRESSURE

### *Effect of Oil Content on the Coefficient of Consolidation*

The effect of oil content on the coefficient of consolidation $c_v$ is shown in Fig. 7. Generally, the values of $c_v$ increased with higher oil contents which peaked at 6% oil contamination. The value of $c_v$ for the natural soil increased from 234 to 1501 at 6% oil content applying 50 kN/m² loading pressure. With further increase in oil content up to 8%, there was a corresponding decrease in the values of $c_v$ to a minimum value of 13. Similar trends were observed at higher loading pressures. The reasons for the increase in values of $c_v$ with higher oil contamination could be due to the initial settlement and extrusion of oil from the soil matrix with increasing loadings through the process of consolidation which is time dependent. However, at 8% oil content the process of compressibility and consolidation occurred simultaneously as the excess oil was extruded from the oil contaminated soil, hence lower values of $c_v$ were recorded.

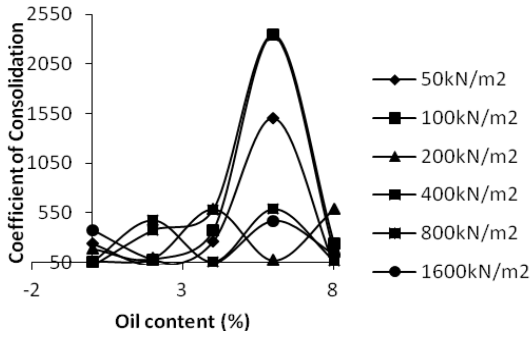


FIG. 7 VARIATION OF COEFFICIENT OF CONSOLIDATION WITH OIL CONTENT

## Conclusion

Based on the results obtained from the implemented investigation the following conclusions can be made:

1. The lateritic soil used is an A-6 or CL soil in AASHTO and USCS classification systems, respectively.
2. The oil used has the following physical properties: specific gravity, flash point, fire point, viscosity and density as, 0.70, 1680C, 2200C, 1.17 cP, and 0.76 g/cm3 respectively.
3. The natural soil had 86.9% fines passing the BS sieve No. 200, with high plastic limit and plasticity index.
4. There was great reduction in the amount of fines fraction with higher doses of oil by dry weight of soil. The percentage of silt size fraction in the natural soil was 86.9% and then reduced to 25.1, 13.6 and 1.4% when contaminated with oil content at 2, 4 and 6% oil contents by dry weight of soil, respectively.

Additionally, from the results of the study, it was observed that the presence of oil in the lateritic soil led to the reduction in the values of UCS, void ratios and the increase in the values of volume compressibility, $M_v$, and coefficients of consolidation, $c_v$. The results clearly showed that oil contamination had serious negative influence on the geotechnical properties of soils which, is not suitable for engineering purposes, would require some remediation or stabilization processes in order to improve the bearing capacity of the affected soil.

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